

Assessment of Terrestrial Carbon Stock: Evaluating Forest Structure and its Carbon Sequestration Potential of the Ecotone Region in *Gama Luma*

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Abstract

Forests globally store an estimated 861 gigatons of Carbon, but deforestation and forest degradation present considerable threats. Bhutan significantly contributes to global climate change efforts, prioritizing carbon sequestration through sustainable forest management. Bhutan's dedication includes maintaining at least 60% forest cover for all times to come. Therefore, such goals highlight the importance of investigating the carbon dynamics in this region. This study explores the carbon sequestration potential of the unexamined ecotone region in Gama Luma. A random sampling method was used, and a total of 30 sampling plots were laid out in 37 hectares of study area. We examined relationships between carbon stock, biomass, and variables such as DBH, Important Value Index, total tree height, basal area, diversity, and tree species density, including an overview of biomass accumulation and carbon sequestration potential across species. Field surveys identified 351 trees from 22 species and 16 families, with *Myrsine capitellata* and *Pinus roxburghii* as the dominant species. The ecotone forest region is young, with trees mostly in the 10 - 20cm DBH class. The findings showed that *Castanopsis tribuloides* had the highest biomass accumulation of 1.690 Mg/ha and carbon stock of 0.845 Mg C/ha, while *Zanthoxylum armatum* had the lowest. A positive correlation ($r = 0.774$, $p < 0.05$) between DBH distribution and carbon sequestration potential was observed. These findings highlight the ecotone region's significant carbon storage capacity and underscores the importance of its conservation and sustainable management for climate change mitigation, offering valuable insights for policymakers and forest managers in Bhutan and other regions.

1. INTRODUCTION

Bhutan significantly contributes to global climate change efforts, prioritizing carbon sequestration through sustainable forest management (Delma et al., 2024). Forests globally store an estimated 861 ± 66 Gt (gigatons) of Carbon (Global Forest Review, 2022), but deforestation and forest degradation present considerable threats (Williams, 2023; Wu et al., 2024). Bhutan, through REDD+ initiatives, sustainable forest management, and the submission of its National Forest Reference Emission Level (FREL) and Forest Reference Level (FRL), aims to reduce emissions from deforestation, manage forests sustainably, and enhance forest carbon stocks (Services, 2020). Bhutan's dedication includes maintaining at least 60% forest cover and achieving carbon neutrality, providing valuable insights for other nations (Seema et al., 2016; Waiba and Dorji, 2024).

Forests serve as both carbon sinks and sources. They sequester carbon through processes like photosynthesis but can release it if degraded (Chen et al., 2021; Ahmed et al., 2024). Protecting and restoring forests is crucial for achieving carbon neutrality (Kumar et al., 2023). Bhutan's biomass and carbon stock evaluation is vital for understanding carbon storage and mitigating climate change. Biomass measures the mass of living organisms, while carbon stock represents the total carbon stored. The IPCC uses a default carbon factor of 0.5 to estimate changes in carbon stock (Meng et al., 2021). Accurate biomass and carbon stock evaluations are essential for overseeing carbon sequestration processes and implementing effective climate change strategies (Dorji et al., 2021; P. Kumar et al., 2023; Ahmed et al., 2024).

Bhutan is renowned for its diverse ecosystems and abundant biodiversity, particularly within its ecotone regions, which serve as critical transition zones between ecosystems (Kark & Rensburg, 2006; Waiba et al., 2024)). These areas support unique species compositions and facilitate gene flow, enhancing genetic diversity and ecosystem resilience (Khandu et al., 2022). Ecotones in Bhutan vary in size and characteristics, providing habitats for "edge" species that thrive on both sides of the ecotone (Kark & Rensburg, 2006). These regions play essential roles in conservation, acting as protective buffers and contributing significantly to carbon sequestration (Sjögersten &

Wookey, 2009). Bhutan's commitment to maintaining carbon neutrality and its extensive forest cover highlights the environmental significance of ecotones like Gama Luma in influencing regional and global carbon dynamics (Samdrup, 2012; Waiba and Dorji, 2024).

This research proposal addresses the gap in evaluating terrestrial carbon stocks and biomass in Gama Luma's ecotone region, where the chirpine ecosystem merges with a broadleaved ecosystem. It analyzes carbon stock, biomass distribution, and related factors to understand ecological and environmental influences on carbon stock. This study will support Bhutan's carbon neutrality efforts and provide valuable insights for climate change mitigation strategies, guiding policy development and ecosystem management practices to policymakers.

The ecotone area in Gama Luma, where chirpine forests merge with broad-leaved forests, is vulnerable to climate change and human activities. Despite its potential to significantly sequester carbon, the ecotone's ability to support biomass and capture terrestrial carbon remains largely unexplored. Bhutan's active participation in REDD + initiatives, commitment to carbon neutrality, and sustainable development goals highlight the importance of investigating the carbon dynamics in this region (Kutter & Crepin, 2022). Assessing carbon stock and biomass in Gama Luma is crucial for understanding its role in climate change mitigation and biodiversity conservation (Hui et al., 2016). This research aims to fill the data gap, guiding conservation efforts and informed decision-making for land use and natural resource management

The objectives of this research are as follows: **1)** To quantify terrestrial biomass accumulation and carbon stock within the ecotone region of Gama Luma in Punakha District; **2)** To conduct a comparative assessment of carbon sequestration among different tree species in Gama Luma.

In order to fulfill the objectives, the following research questions are framed: i) What is the distribution pattern of tree species and their relative dominance in the Gama Luma Forest area of Punakha, Bhutan? ii) What is the relationship between forest stand structure, species composition, and carbon sequestration potential in the research site? Finally, iii) How does the diameter at breast height (DBH) class influence biomass accumulation and carbon sequestration potential? The above questions will provide the basis for achieving legitimate empirical data to accomplish the goal of this study.

2. MATERIALS AND METHODS

2.1 Study Area

Gama Luma is located in the Punakha district in the Western part of the country. The Gama Luma serves as an excellent viewpoint for two significant rivers, the *Mo Chhu* (referred to as the Mother River) and the *Pho Chhu* (known as the Father River), which converge and form *Puna Tsang Chhu*, that play a vital role in supporting the local agriculture.

In terms of climate, *Gama Luma* experiences a subtropical climate, with its seasons clearly defined. Summers are warm and marked by generous rainfall. The monsoon season, characterized by heavy rainfall, contributes to the luxuriant and vibrant greenery that characterizes the area (Wangdi & Kastars, 2012).

2.2 Materials

A compass and GPS (Global Positioning System) were employed to ascertain direction and document coordinates. A smartphone loaded with a SW map alongside the GPS was also used to track the plots. A measuring tape was

also used to compute the distance. Tree heights were measured using a clinometer, and tree diameter at breast height (DBH) was determined using the Diameter tape.

2.3 Sampling Design and Measurement

For this study, the random sampling method was used, and a total of 30 sampling plots were laid out in 37 hectares of the study area. The allocation of sampling plots on the map was randomized with the assistance of ArcGIS. Subsequently, the coordinates corresponding to these plots were documented on the map and transferred into the GPS device and SW map on the smartphone during ground truthing and field survey. A total number of plots were assigned, taking 4% as sampling intensity by dividing the study area from the desired plot size as carried out in a published work by Tshomo (2021):

TSP = TA/PSEq. (1)

Where TSP: Total number of sampling plot

TA: Total area of study site

PS: Plot size

Calculation

Total area = 370,000 m²

Therefore, number of sampling plot = 370,000 m²/500 m² = 740

Taking 4% sampling intensity = 4/100*740 = 29.6 ≈ 30 sampling plots

Tree measurement: All trees with a diameter at breast height (DBH) of 10 cm and greater were measured. The measurements were taken at a height of 1.3 meters above the ground within a circular plot with a radius of 12.62 meters. The DBH of the trees were measured using diameter tapes, while the tree heights were measured using a clinometer.

2.4 Data Analysis

2.4.1 Species-specific Volume:

The species-specific volume equations developed by the Forest Survey of India, FSI (1996) was used.

The following formulas were employed as prescribed by the Good Practices Guidance (GPG) of the Intergovernmental Panel on Climate Change (Borges et al., 2022) to quantify biomass and carbon stock:

Bole Biomass, **W = (V x WD) / (Plot size x 10)**

- Above Ground Biomass, **AGB = W x BEF (1.59)**
- Below Ground Biomass, **BGB = AGB x 0.26**
- Dead Organic Matter, **DOM = (AGB + BGB) x 0.11**
- Total Biomass, **TB = AGB + BGB + DOM**
- Carbon stock, **C = TB x 0.5**

2.4.2 Statistical Analysis

Data were collected plot-wise and compiled in Microsoft Excel (2016) by species to calculate biomass and carbon stock, then processed using SPSS (Version 26.0) for inferential analysis. A Shapiro-Wilk test indicated non-normal data distribution, prompting the use of a Spearman correlation test to measure the relationship between DBH class and carbon sequestration. Analytical tests in Excel examined relationships between carbon stock, biomass, and variables such as DBH, Important Value Index, total tree height, basal area, diversity, and tree species density. Descriptive analysis provided an overview of biomass accumulation and carbon sequestration potential across species, with significance levels set at $p < 0.05$ for all tests. Graphs and visual representations were generated using these software tools.

3. RESULTS AND DISCUSSIONS

3.1 Floristic Composition in Gama Luma

The study aimed to quantify terrestrial biomass accumulation and carbon stock in the ecotone region of Gama Luma, Punakha District. A total of 351 trees from 16 families and 22 species were analyzed, with Myrsinaceae and Pinaceae being the most common families. Trees with a DBH of less than 10 cm were excluded. *Myrsine capitellata* was the dominant species according to the Important Value Index (IVI) of 67.689, followed by *Pinus roxburghii* at 37.151, while *Zanthoxylum armatum* was the least dominant at 1.275 (refer Table 1). Fagaceae had the most species (four), followed by Pentaphylacaceae, Pinaceae, and Rosaceae, which had two species each, and the remaining families had one species each.

Table 1: Floristic composition of the study area in Gama Luma

Tree species	ABA (cm ² /ha)	Relative dominance	Relative density	Relative frequency	IVI	Ranks
Bc	10.101	3.938	3.419	4.386	11.743	9
Bj	19.635	0.638	0.285	0.877	1.800	17
Cs	3.170	0.206	0.570	0.877	1.653	19
Ct	14.801	11.541	6.838	7.018	25.396	6
Ds	3.528	0.115	0.285	0.877	1.277	21
Di	3.646	0.237	0.570	0.877	1.684	18
Ea	6.961	1.357	1.709	3.509	6.575	11
Ec	14.037	1.368	0.855	1.754	3.977	12
Ep	3.047	0.198	0.570	1.754	2.522	16
Mc	4.201	16.242	33.903	17.544	67.689	1
Pr	12.671	17.290	11.966	7.895	37.151	2
Pw	9.021	0.293	0.285	0.877	1.455	20
Pc	34.226	2.224	0.570	0.877	3.671	13
Qg	12.060	5.485	3.989	6.140	15.614	7
Qgr	14.243	12.956	7.977	12.281	33.214	3
Ql	15.642	12.197	6.838	7.895	26.929	5
Ra	5.390	7.004	11.396	8.772	27.172	4
Sw	8.235	3.745	3.989	5.263	12.997	8
Sp	4.859	0.316	0.570	1.754	2.640	15
Sc	19.635	1.276	0.570	1.754	3.600	14
Za	3.462	0.112	0.285	0.877	1.275	22
Zi	4.315	1.262	2.564	6.140	9.966	10
Total	226.886	100.000	100.000	100.000	300.000	

Abbreviations: ABA- Average Basal Area, IVI- Important Value Index, **Bc**- *Benthamidia capitata*, **Bj**- *Bischovia javanica*, **Cs**- *Carpinus spp*, **Ds**- *Dalbergia sericea*, **Di**- *Docynia indica*, **Ea**- *Eurya acumionata*, **Ec**- *Eurya cerasifolia*, **Ep**- *Exbucklandia populnea*, **Mc**- *Myrsine capitellata*, **Pr**- *Pinus roxburghii*, **Pw**- *Pinus wallichiana*, **Pc**- *Pyracantha crenulate*, **Qg**- *Quercus glauca*, **Qgr**- *Quercus graffithii*, **Ql**- *Quercus lanata*, **Ra**- *Rhododendron arboretum*, **Sw**- *Schima wallichii*, **Sp**- *Symplocos paniculate*, **Sc**- *Syzigium cumini*, **Za**- *Zanthoxylum armatum*, **Zi**- *Ziziphus incurve*

3.2 Species-wise total biomass and carbon stock comparison

The study in the ecotone region of Gama Luma recorded a total of twenty-two tree species with a combined biomass of 7.890 Mg/ha, converting to a carbon stock of 3.945 Mg C/ha (ref. Table 2). *Castanopsis tribuloides* was the dominant species with a biomass of 1.690 Mg/ha and a carbon content of 0.845 Mg C/ha, while *Zanthoxylum armatum* had the lowest biomass and carbon sequestration potential at 0.004 Mg/ha and 0.002 Mg C/ha, respectively (ref. Table 2). This analysis highlights the significant contribution of *Castanopsis tribuloides* to carbon storage, providing valuable insights into the relationship between forest stand structure, species composition, and carbon sequestration potential. The study aligns with similar research in Nepal's Chitwan-Annapurna Landscape, emphasizing the importance of understanding species-specific carbon sequestration capacities to address climate change effectively (Subedi et al., 2016).

Table 2: Species-wise biomass (Mg/ha) accumulation and carbon (Mg C/ha) sequestration potential

	Above ground		Below ground		Dead Organic Matter		Total	
Species	Biomass	Carbon	Biomass	Carbon	Biomass	Carbon	Biomass	Carbon
	(Mg/ha)	(MgC/ha)	(Mg/ha)	(MgC/ha)	(Mg/ha)	(MgC/ha)	(Mg/ha)	(MgC/ha)
Bc	0.363	0.182	0.094	0.047	0.050	0.025	0.508	0.254
Bj	0.053	0.026	0.014	0.007	0.007	0.004	0.074	0.037
Cs	0.007	0.004	0.002	0.001	0.001	0.001	0.010	0.005
Ct	1.208	0.604	0.314	0.157	0.167	0.084	1.690	0.845
Ds	0.007	0.004	0.002	0.001	0.001	0.001	0.010	0.005
Di	0.008	0.004	0.002	0.001	0.001	0.001	0.011	0.006
Ea	0.079	0.040	0.021	0.010	0.011	0.005	0.111	0.055
Ec	0.100	0.050	0.026	0.013	0.014	0.007	0.140	0.070
Ep	0.010	0.005	0.003	0.001	0.001	0.001	0.014	0.007
Mc	0.935	0.467	0.243	0.122	0.130	0.065	1.307	0.654
Pr	0.458	0.229	0.119	0.060	0.064	0.032	0.641	0.320
Pw	0.168	0.084	0.044	0.022	0.023	0.012	0.236	0.118
Pc	0.266	0.133	0.069	0.035	0.037	0.018	0.372	0.186
Qg	0.287	0.143	0.075	0.037	0.040	0.020	0.401	0.201
Qgr	0.614	0.307	0.160	0.080	0.085	0.043	0.859	0.429
Ql	0.533	0.266	0.138	0.069	0.074	0.037	0.745	0.372
Ra	0.158	0.079	0.041	0.020	0.022	0.011	0.220	0.110
Sw	0.182	0.091	0.047	0.024	0.025	0.013	0.254	0.127
Sp	0.015	0.007	0.004	0.002	0.002	0.001	0.021	0.010
Sc	0.110	0.055	0.029	0.014	0.015	0.008	0.154	0.077
Za	0.003	0.002	0.001	0.000	0.000	0.000	0.004	0.002
Zi	0.077	0.039	0.020	0.010	0.011	0.005	0.108	0.054
Mean	0.256	0.128	0.067	0.033	0.036	0.018	0.359	0.179
SD (Standard Deviation)	±0.321	±0.161	±0.084	±0.042	±0.045	±0.022	±0.449	±0.225

3.2.1 Total Biomass (TB) accumulation (Bole Biomass [BB], Above Ground Biomass [AGB], Below Ground Biomass [BGB] and Dead Organic Matter [DOM]) of Gama Luma.

The study area exhibited a total biomass accumulation of 11.438 Mg/ha, with species-specific contributions ranging from 0.782 to 3.548 Mg/ha. Biomass acts as the main organic carbon reservoir in forest ecosystems,

influenced by topography, climate, wood density, and volume equations. Ali et al. (2023) further explored the factors affecting biomass accumulation, highlighting plant characteristics such as morphology, genetics, physiology, and environmental factors like air temperature, humidity, light intensity, shading, and soil conditions. The study also underscored the importance of management practices in forestry, silviculture, and ecosystem protection in enhancing biomass production.

3.3 Carbon sequestration potential of Gama Luma study site

The study site in Gama Luma showed an overall carbon sequestration potential of 5.719 Mg C/ha, with individual biomass contributing between 0.391 and 2.821 Mg C/ha (ref. Table 3). Among different species, carbon sequestration varied from 0.003 to 1.225 Mg C/ha. The biomass accumulation and carbon stock quantity is less for the study site since data were collected across 30 sampled plots containing trees with DBH greater than 10 cm. The young age of the forest resulted in a smaller pool for analysis. Despite this limitation, the study provides valuable insights into species with the potential for biomass accumulation and carbon sequestration, aiding in developing effective forest management strategies.

Similarly, in Maleka Parish, Uganda, a research initiative explored the potential for carbon sequestration within smallholder farmlands of 60 farms (including herbs, shrubs, and trees). Results indicated an average of 7.8 Mg C/ha sequestered (Menteri, 2014). This small-scale investigation helped farmers participate in carbon markets, benefiting the environment and their livelihoods.

Table 3: Total biomass (Mg/ha) and carbon (Mg C/ha) sequestration potential

Species	BB	AGB	BGB	DOM	Total biomass	Total carbon
Bc	0.228	0.363	0.094	0.050	0.736	0.368
Bj	0.033	0.053	0.014	0.007	0.107	0.053
Cs	0.005	0.007	0.002	0.001	0.015	0.007
Ct	0.760	1.208	0.314	0.167	2.450	1.225
Ds	0.005	0.007	0.002	0.001	0.015	0.008
Di	0.005	0.008	0.002	0.001	0.016	0.008
Ea	0.050	0.079	0.021	0.011	0.161	0.080
Ec	0.063	0.100	0.026	0.014	0.204	0.102
Ep	0.006	0.010	0.003	0.001	0.020	0.010
Mc	0.588	0.935	0.243	0.130	1.895	0.948
Pr	0.288	0.458	0.119	0.064	0.929	0.464
Pw	0.106	0.168	0.044	0.023	0.342	0.171
Pc	0.167	0.266	0.069	0.037	0.539	0.269
Qg	0.180	0.287	0.075	0.040	0.581	0.291
Qgr	0.386	0.614	0.160	0.085	1.245	0.623
Ql	0.335	0.533	0.138	0.074	1.080	0.540
Ra	0.099	0.158	0.041	0.022	0.319	0.160
Sw	0.114	0.182	0.047	0.025	0.368	0.184
Sp	0.009	0.015	0.004	0.002	0.030	0.015
Sc	0.069	0.110	0.029	0.015	0.224	0.112
Za	0.002	0.003	0.001	0.000	0.006	0.003
Zi	0.049	0.077	0.020	0.011	0.157	0.078
Total biomass	3.548	5.641	1.467	0.782	11.438	-
Total carbon	1.774	2.821	0.733	0.391	5.719	-

Abbreviations: **BB**- Bole Biomass, **AGB**- Above Ground Biomass, **BGB**- Below Ground Biomass, **DOM**- Dead Organic Matter

3.4 Number of trees distributed in DBH class

The study conducted in Gama Luma, Bhutan, examined the distribution of tree diameters at breast height (DBH), revealing a diverse range from 10 to 116.3 cm. Notably, the majority of trees fell within the 10-20 cm DBH class, totaling 168 trees, followed by 72 trees in the 21-30 cm DBH class. In contrast, very few trees were found in the larger DBH classes of 101-110 cm and 111-120 cm, each with only one tree, indicating a forest stand skewed towards smaller diameters typical of a young forest (Figure 4).

3.5 Diameter class (DBH) distribution and biomass accumulation

The study conducted in Gama Luma, Bhutan, analyzed the relationship between diameter at breast height (DBH) classes and biomass accumulation, revealing significant variations across different tree size categories. The DBH class ranging from 10 to 20 cm emerged as dominant in Above Ground Biomass (AGB), recording 1.326 Mg/ha, followed by the 41-50 cm class with 0.994 Mg/ha. Accordingly, the 10-20 cm DBH class also exhibited the highest accumulations in Bole Biomass (BB), Below Ground Biomass (BGB), and Dead Organic Matter (DOM), highlighting its importance in overall biomass storage within the forest ecosystem (ref. Figure 5). In contrast, the largest DBH class (111-120 cm) showed significantly lower biomass accumulations across all categories, indicating the scarcity of older and larger trees in the study area, which predominantly consists of young forest stands.

These findings underscore the impact of forest age structure on biomass accumulation and carbon storage potential. The prevalence of smaller DBH classes with higher biomass accumulations reflects the young nature of the forest in Gama Luma. This analysis directly addresses the study's objective of quantifying terrestrial biomass accumulation and carbon stock in the ecotone region, offering insights into how different DBH classes influence carbon dynamics and emphasizing the importance of forest management strategies that promote diverse age structures for enhancing carbon sequestration efforts.

Table 4: Biomass (mg/ha) and carbon (mg C/ha) in DBH class

DBH class (cm)	BB	AGB	BGB	DOM	Total biomass (Mg/ha)	Total carbon Mg C/ha)
10- 20	0.834	1.326	0.345	0.184	1.855	0.927
21-30	0.431	0.685	0.178	0.095	0.958	0.479
31-40	0.526	0.837	0.218	0.116	1.170	0.585
41-50	0.625	0.994	0.258	0.138	1.390	0.695
51-60	0.586	0.932	0.242	0.129	1.304	0.652
61-70	0.127	0.202	0.053	0.028	0.283	0.141
71-80	0.119	0.190	0.049	0.026	0.265	0.133
81-90	0.036	0.058	0.015	0.008	0.081	0.040
91-100	0.251	0.400	0.104	0.055	0.559	0.279
101-110	0.008	0.012	0.003	0.002	0.017	0.008
111-120	0.004	0.006	0.001	0.001	0.008	0.004
Total	0.295	0.469	0.122	0.065	0.657	0.328

3.6 Diameter class and carbon sequestration

The study in Gama Luma, Bhutan, investigated the carbon sequestration potential across various diameters at breast height (DBH) classes, highlighting that smaller to medium-sized trees, particularly those in the 10-20 cm and

41-50 cm DBH classes, exhibited the highest capability for carbon storage. Specifically, the 10-20 cm DBH class showed the highest carbon sequestration potential at 0.927 Mg C/ha, followed closely by the 41-50 cm class at 0.695 Mg C/ha. Larger trees in the DBH classes exceeding 71 cm up to 111-120 cm demonstrated lower carbon stocks due to fewer individual trees in these size categories. This pattern underscores the importance of tree size in determining carbon storage capacity within the forest ecosystem of Gama Luma.

Comparative studies from Himachal Pradesh and Myanmar provide additional context on how DBH size influences carbon sequestration potential in forest ecosystems. The research from Himachal Pradesh indicated that the 21-30 cm DBH class exhibited the greatest capability for carbon storage across diverse forest locations, emphasizing the role of mature forest stands in storing larger amounts of carbon compared to younger stands. In contrast, findings from Myanmar's mangrove plantations suggested that trees in the 11-20 cm DBH range showed higher carbon storage potential than those in other DBH size classes, highlighting the variability in carbon sequestration potential influenced by both species' composition and tree size. These insights contribute to a broader understanding of the relationship between forest structure, species characteristics, and carbon dynamics, which are essential for effective forest management and climate change mitigation strategies.

3.7 Relationship analysis between DBH and Carbon stock (Mg C/ha)

Spearman correlation test generated a statistically significant relationship between the DBH distribution and carbon (C) sequestration potential with $r = 0.774^{**}$ at $p < 0.05$ (2-tailed). It suggests that the tendency for carbon sequestration increases as the diameter at breast height of trees increases.

Understanding the correlation between diameter at breast height (DBH) distribution and carbon storage is crucial for implementing successful forest management techniques and strategies to combat climate change (Dorji et al., 2021; Ahmed et al., 2023). Different DBH classes signify different phases of tree development and biomass accumulation, influencing forests' overall capacity to sequester carbon.

Examining the relationship between diameter class and carbon sequestration potential directly addresses the research question of how diameter at breast height (DBH) class influences biomass accumulation and carbon sequestration potential. The statistically significant correlation between DBH distribution and carbon sequestration underscores the importance of considering tree size in forest management strategies to enhance carbon storage.

4. CONCLUSIONS AND RECOMMENDATIONS

This study addressed critical gaps in our understanding of terrestrial biomass accumulation and carbon stock dynamics within the ecotone region of Gama Luma in Punakha District. The research provided comprehensive insights into carbon sequestration processes by focusing on species composition, forest stand structure, and diameter at breast height (DBH) class. The dominance of *Myrsine capitellata* and *Pinus roxburghii* highlighted the ecotone's unique blend of broadleaf and conifer species, contributing distinctively to biomass accumulation and carbon storage. The prevalence of young forest stands indicated ongoing regeneration processes, shaping the region's ecological resilience and carbon dynamics over time.

Furthermore, the study underscored the pivotal role of *Castanopsis tribuloides* in biomass and carbon sequestration within Gama Luma ecotone forest region. This species contributed significantly to above-ground

biomass (AGB) and carbon stocks, emphasizing its importance in enhancing forest carbon storage. The correlation between DBH class and carbon sequestration potential underscored that larger trees possess a greater capacity for carbon storage, reinforcing the importance of considering tree size in forest management strategies to maximize carbon sequestration and mitigate climate change impacts.

These findings have substantial implications for forest management and environmental policy in Bhutan. They provide a foundation for informed decision-making in sustainable forest management practices promoting biodiversity conservation and carbon sequestration goals. By acknowledging the study's limitations, such as its focus on above-ground biomass and the young age of sampled forests, future research can expand on these insights. Exploring soil organic carbon contributions, assessing long-term carbon dynamics, and conducting comparative studies across diverse ecological settings will further advance our understanding of forest ecosystem resilience and carbon sequestration potential in ecotone regions like Gama Luma.

Declarations

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Conflict of Interest: The authors declare no conflict of interest.

Author contribution statement: Study conception and design by **KTR & YD**; Methodology Implementation by **KTR & YD**; Data collection by **KTR**; Data analysis/Interpretation by **KTR, YD & TT**; Manuscript writing/ revision by **KTR, YD & TT**. All authors gave final approval.

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Figures

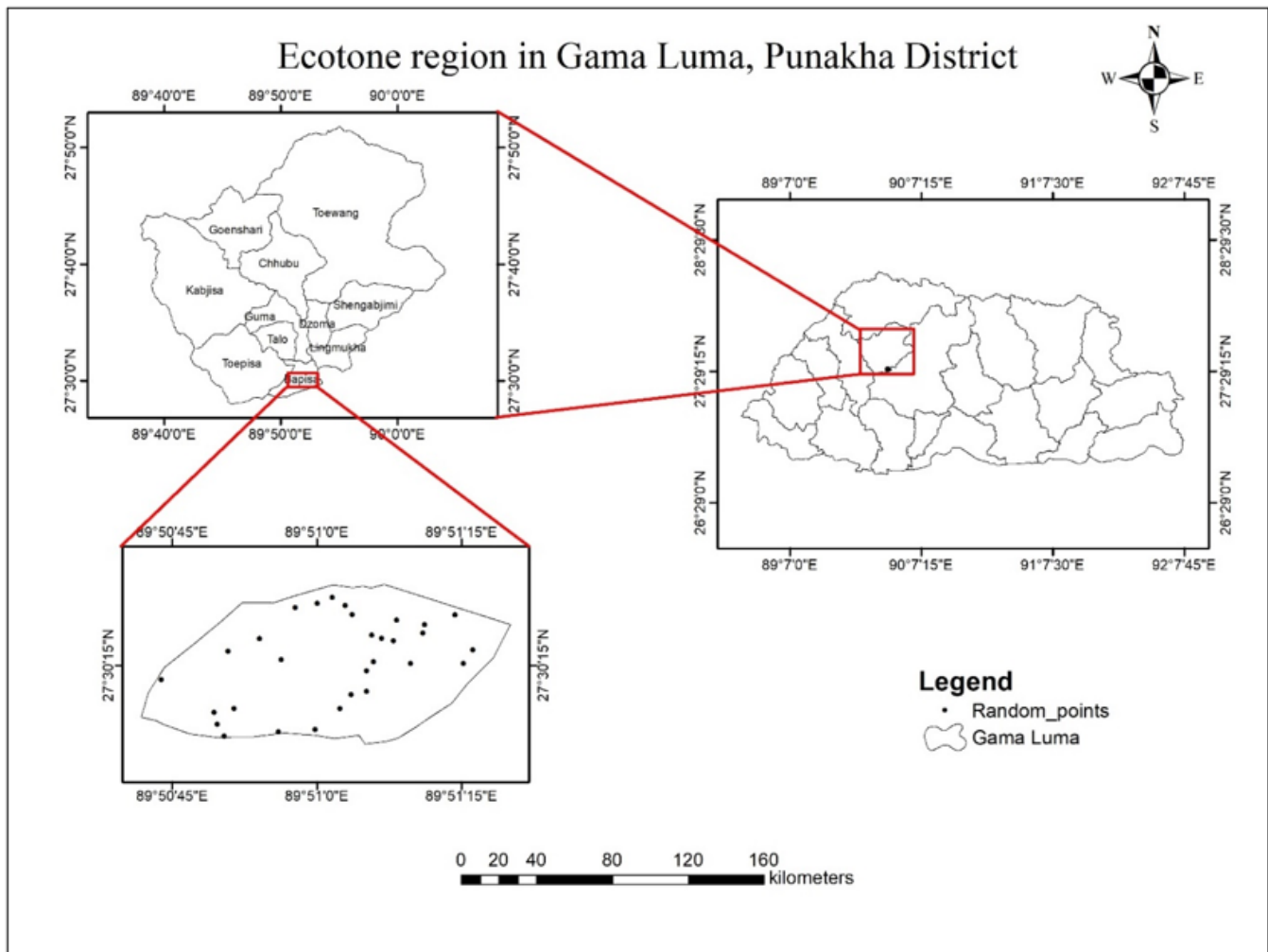


Figure 1

Map depicting study area with randomly sampled plots

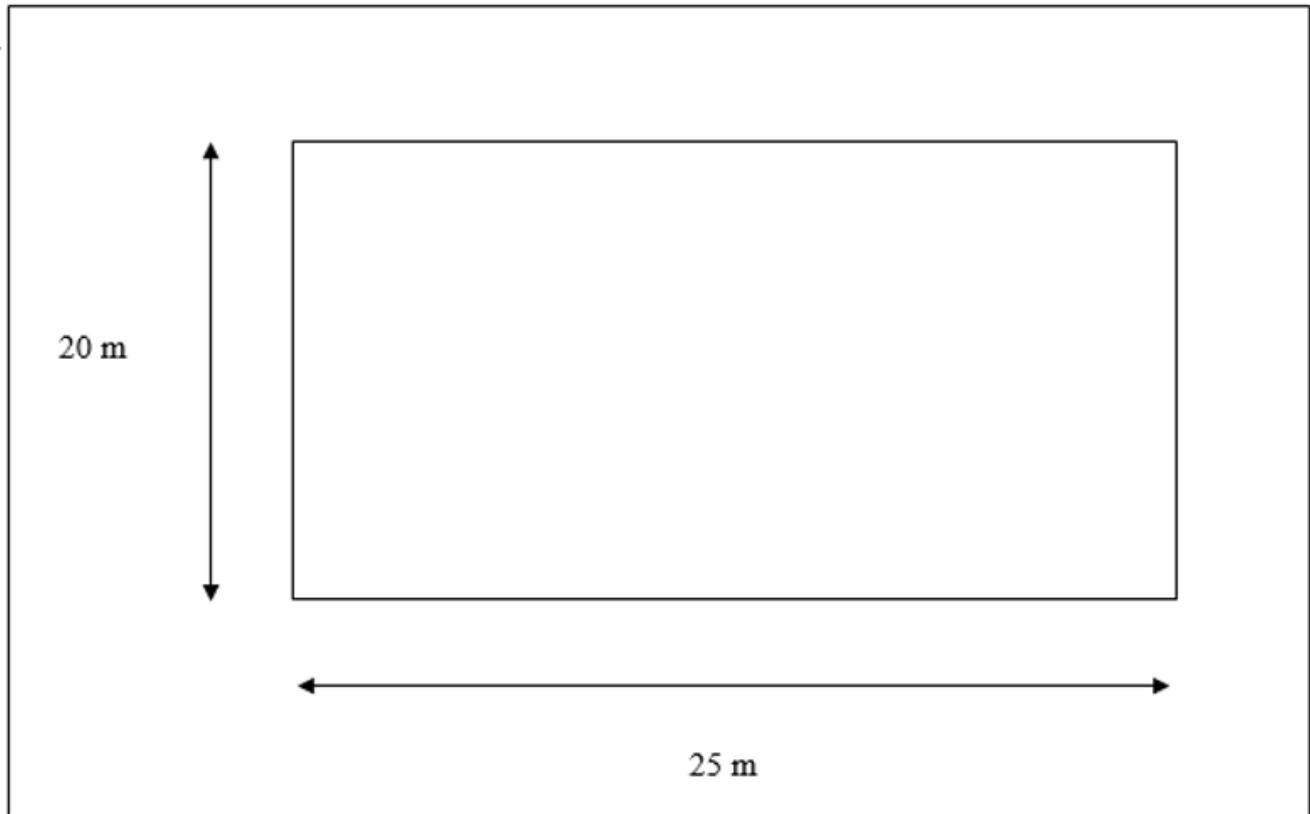


Figure 2

Plot layout with its measurement

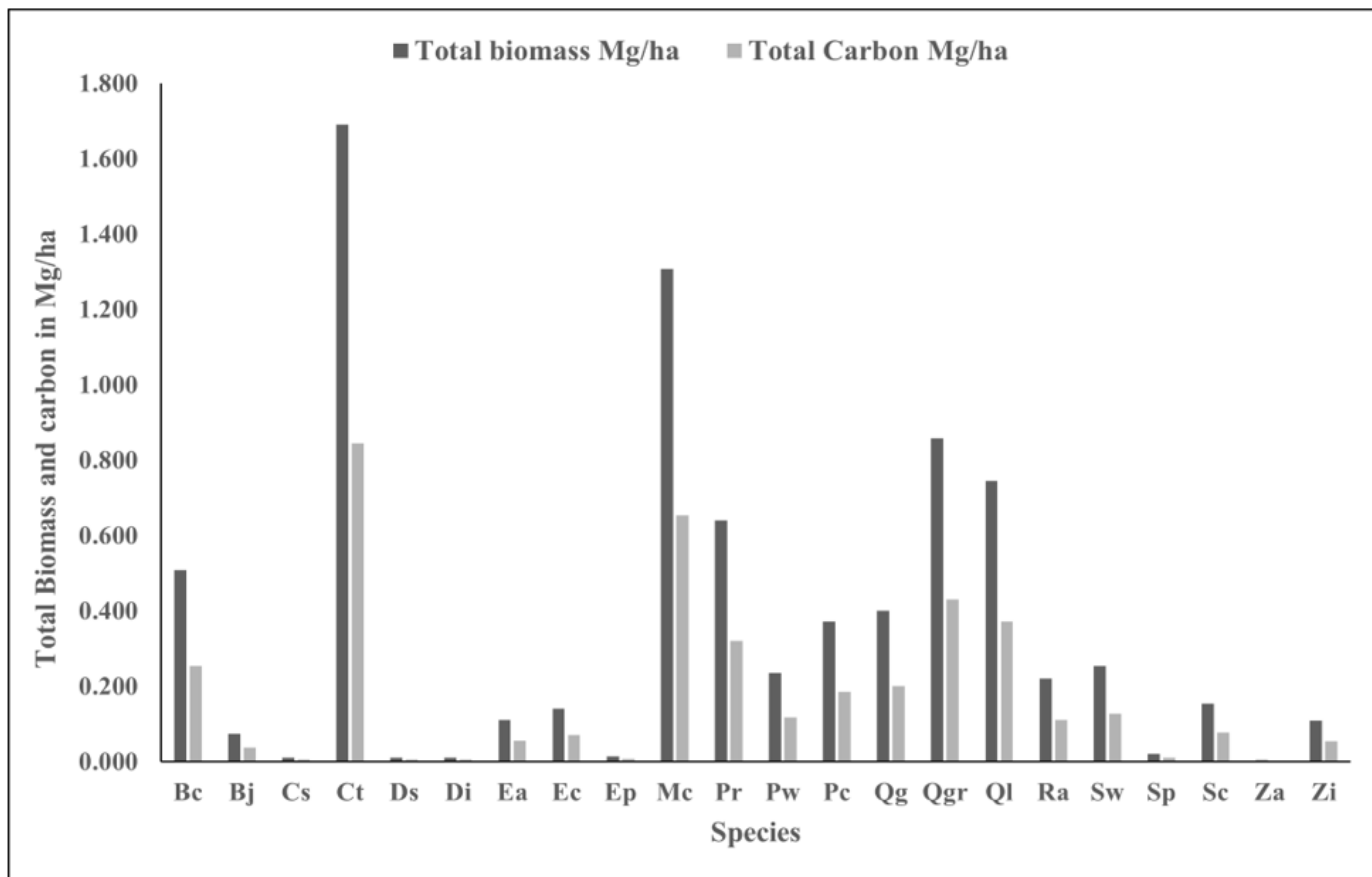


Figure 3

Species-wise total carbon sequestration and biomass accumulation in Mg/ha.

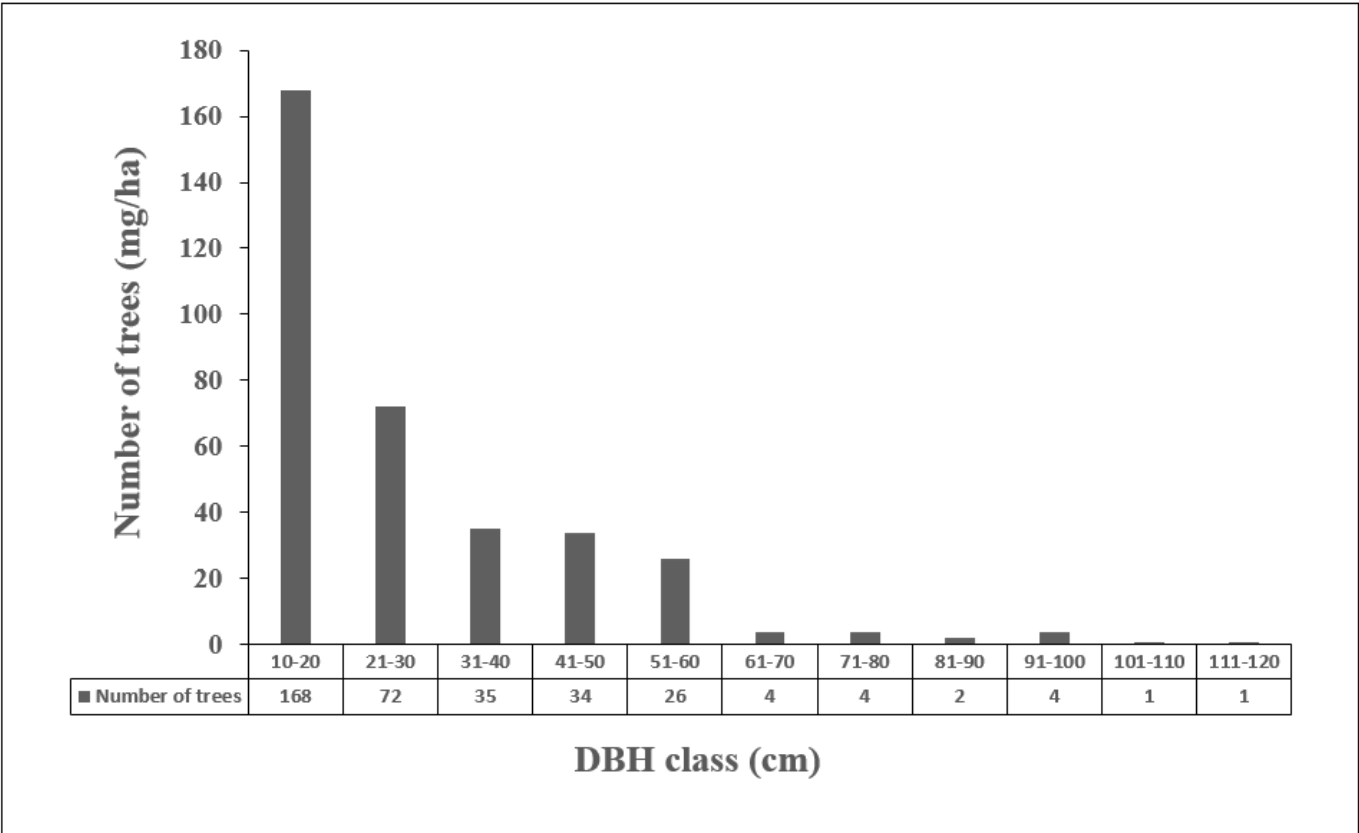


Figure 4

Number of trees in different DBH size classes

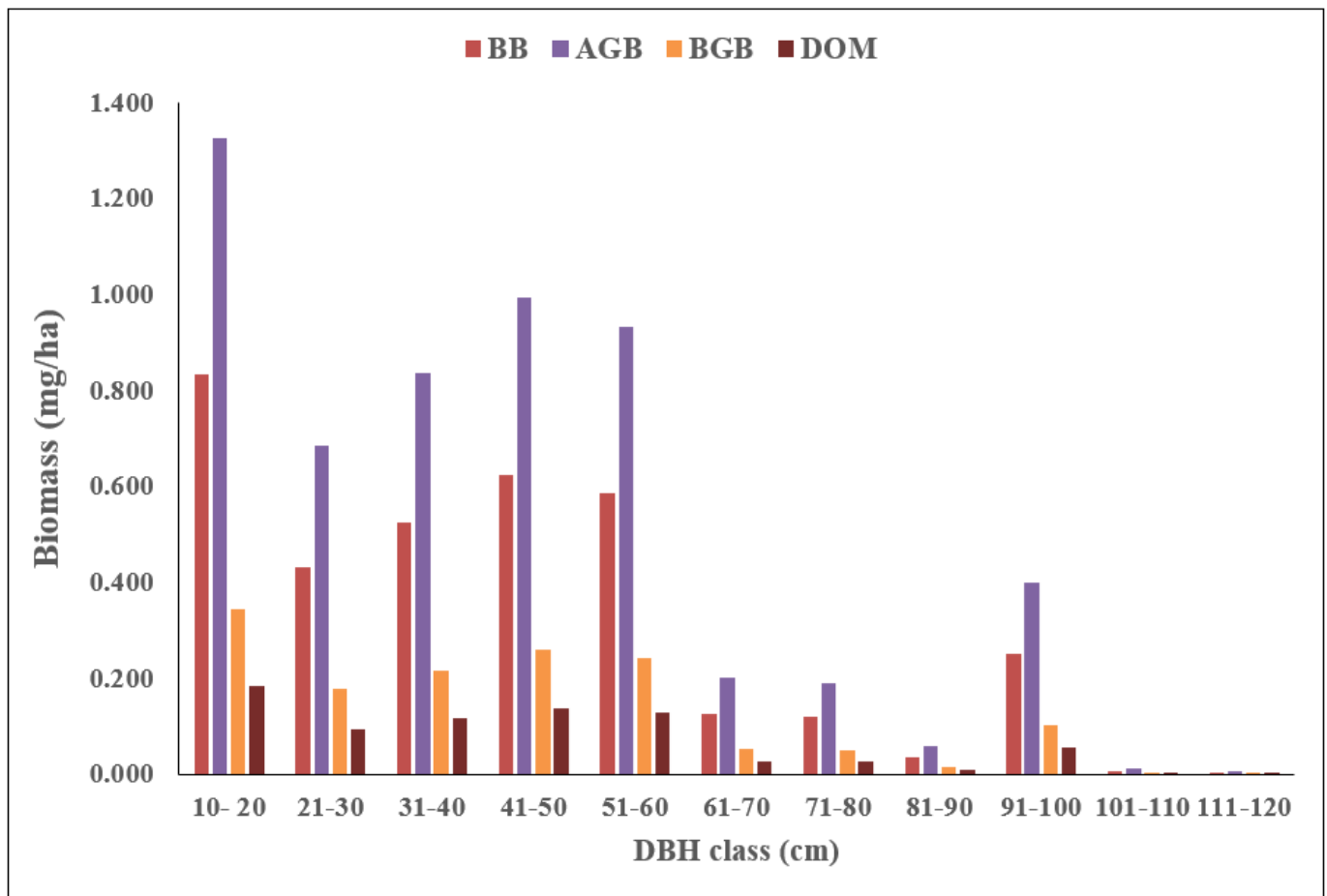


Figure 5

Different Forest biomass with DBH class

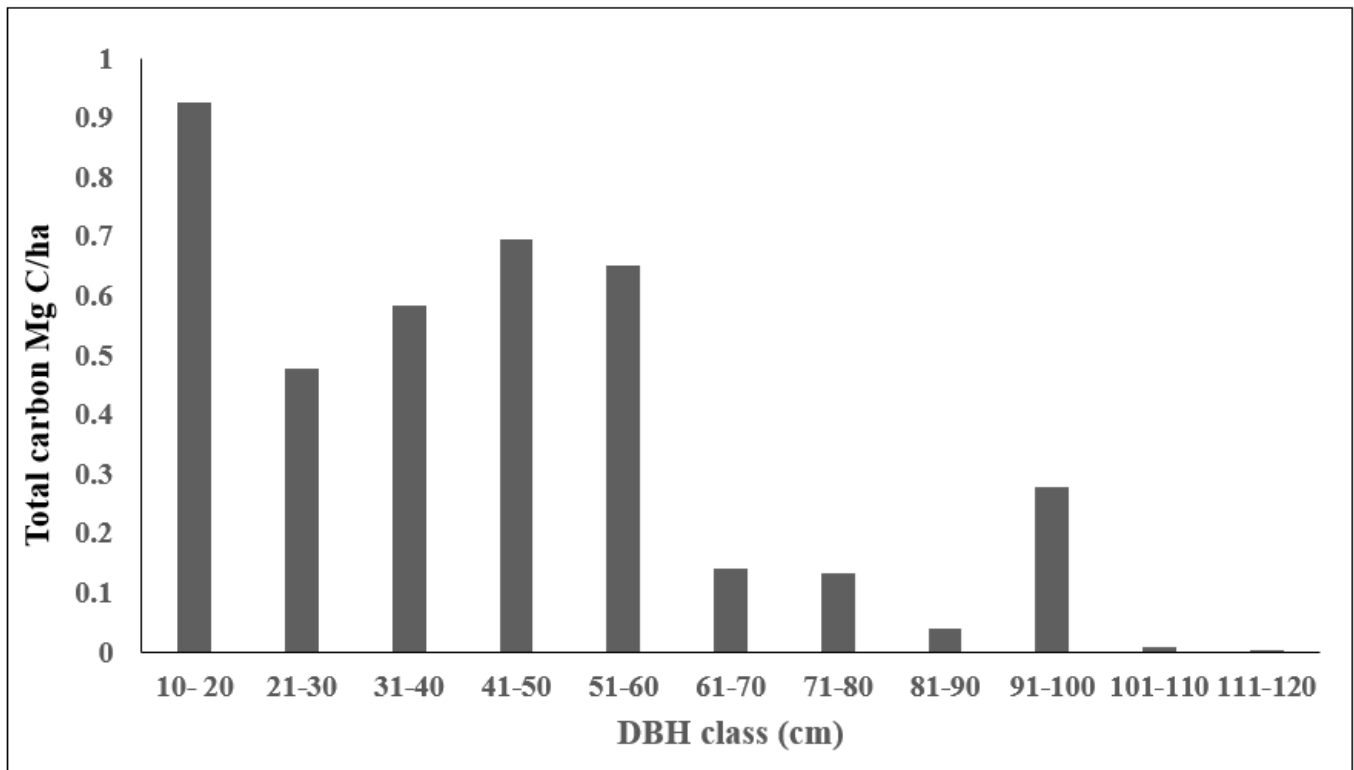


Figure 6

Total carbon sequestration in DBH classes